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An Assessment of the Properties of Internal Combustion Engine Lubricants Using an Onboard Sensor

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Outline

- Goal and motivation
- Background
- Research objectives
- Research methodology
 - Bench-top experiments
 - Engine experiments
- Conclusions



Goal and Motivation

- Monitor lubricant degradation in internal combustion engines through direct, in-situ measurement of lubricant properties
- Benefits
 - Cost and energy usage
 - Lubrication improvements may save up to 20% of the total annual energy consumed by vehicles in the US (~14 billion US dollars)
 - Logistics
 - Tailor oil change intervals to actual vehicle needs
 - Environmental



Background

- Current Methods

- Algorithms based on driver inputs or supplemented with oil property measurements (e.g., dielectric constant)

- Disadvantages

- Contamination might be overlooked
- Over or underestimation of oil change interval

Property	Condemning Limits
Viscosity @ 100°C	10-18 cSt From +25% to -18% ± viscosity grade from new oil
TBN	0.5-4 mg KOH/g -50%
Dielectric Constant	0.01 0.2

- Needs and Challenges

- Measure oil properties accurately, directly and in-situ
- Validate threshold values indicative of oil degradation
- Identify potential causes of measured lubricant condition



Research Objectives

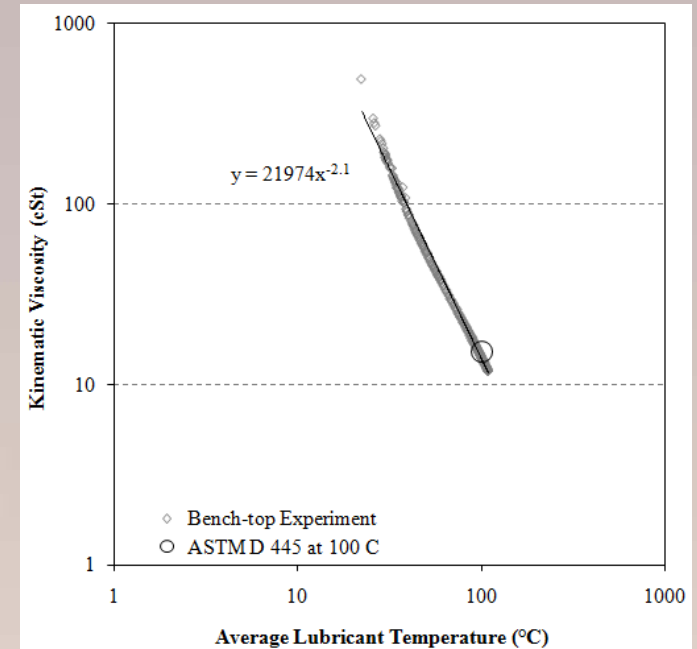
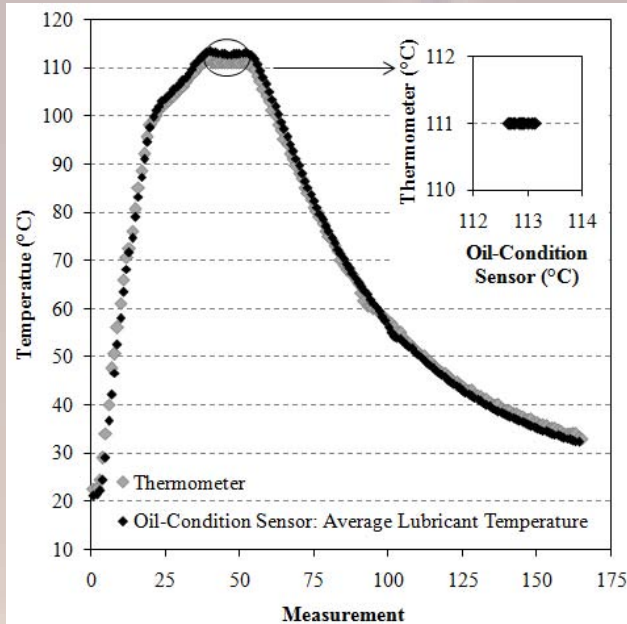
- Quantify the accuracy and precision of lubricant property measurements from an on-board oil-condition sensor
- Correlate changes in the physical properties of the lubricant with likely causes of oil degradation
- Quantify changes in the physical properties of the lubricant with respect to engine operating time



Research Methodology

- Properties measured by the sensor
 - Temperature (55°C to 150°C)
 - Density (0 to 1.5 g/cm³)
 - Viscosity (0 to >50 cP)
 - Dielectric Constant (1.00 to 6.00)
- Lubricant type
 - Rotella T 15W-40
- Bench-top experiments
 - Quantify accuracy of sensor output
 - ASTM standards or reference instruments
- Engine experiments
 - Monitor properties changes with respect to engine operating time

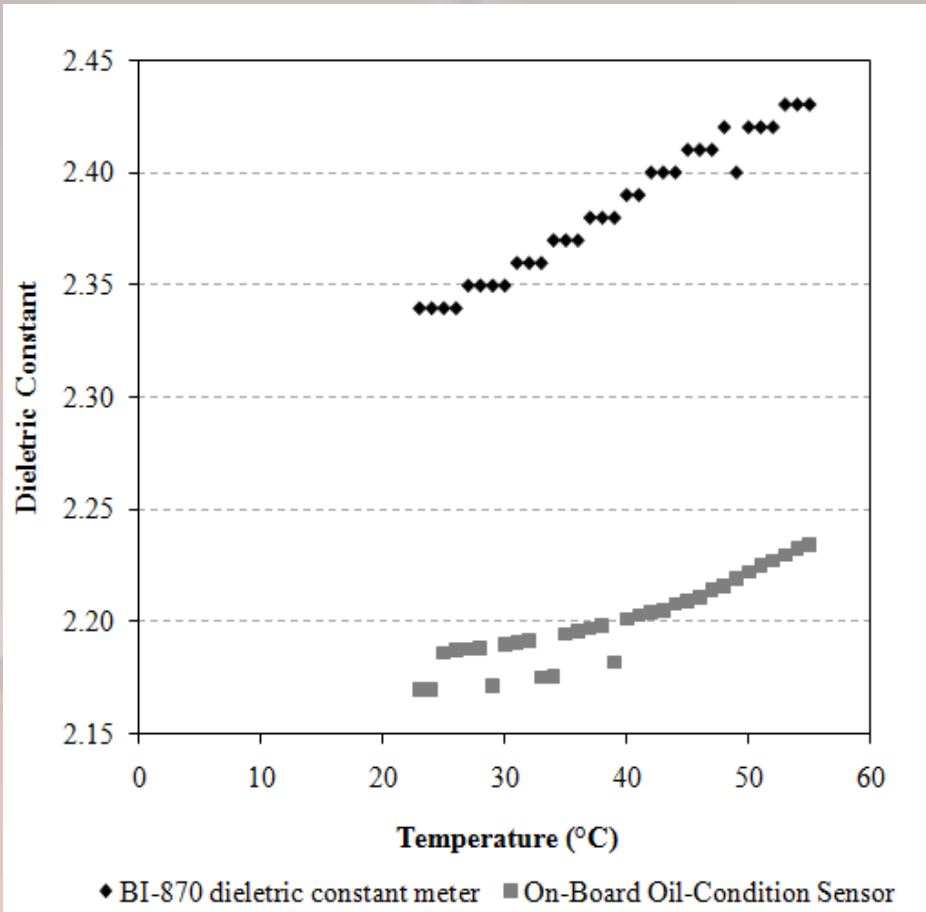
Results from Bench-Top Experiments: Temperature and Density



- Sensor requires ~20 min to reach thermal equilibrium
- Agreement with reference reading to within 2°C
- Viscosity measurements conducted with the sensor are within 6% of ASTM D445 values

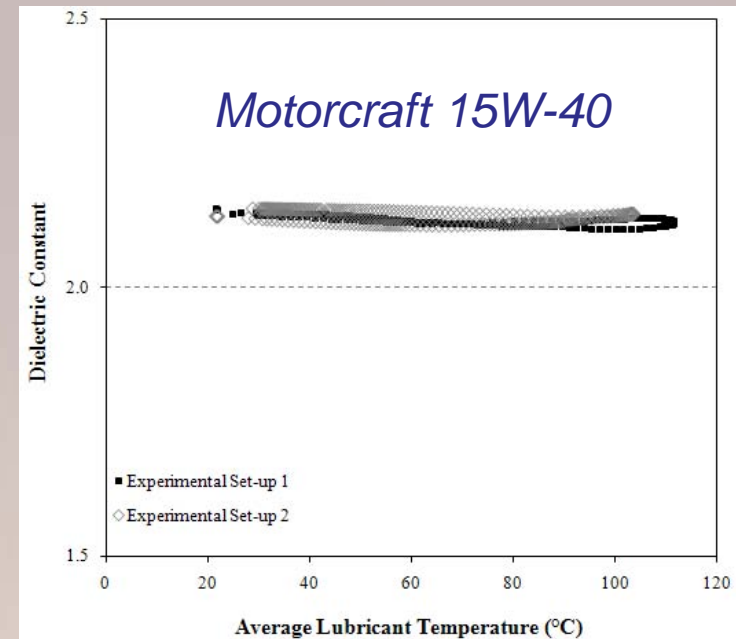
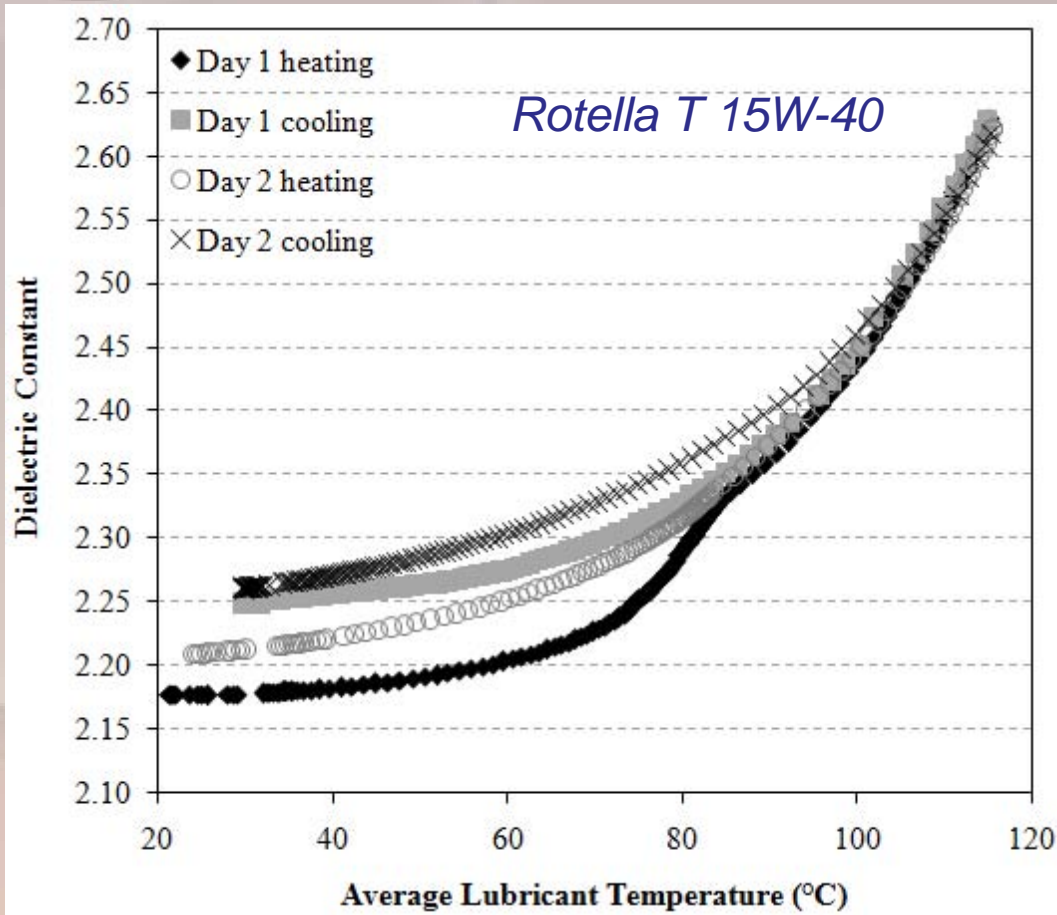


Results: Dielectric Constant



- Sensor output compared to a reference instrument (Brookhaven's BI-870 dielectric constant meter)
- Accuracy of the reference instrument validated a priori
- Sensor reading ~ 6.5% less than reference instrument

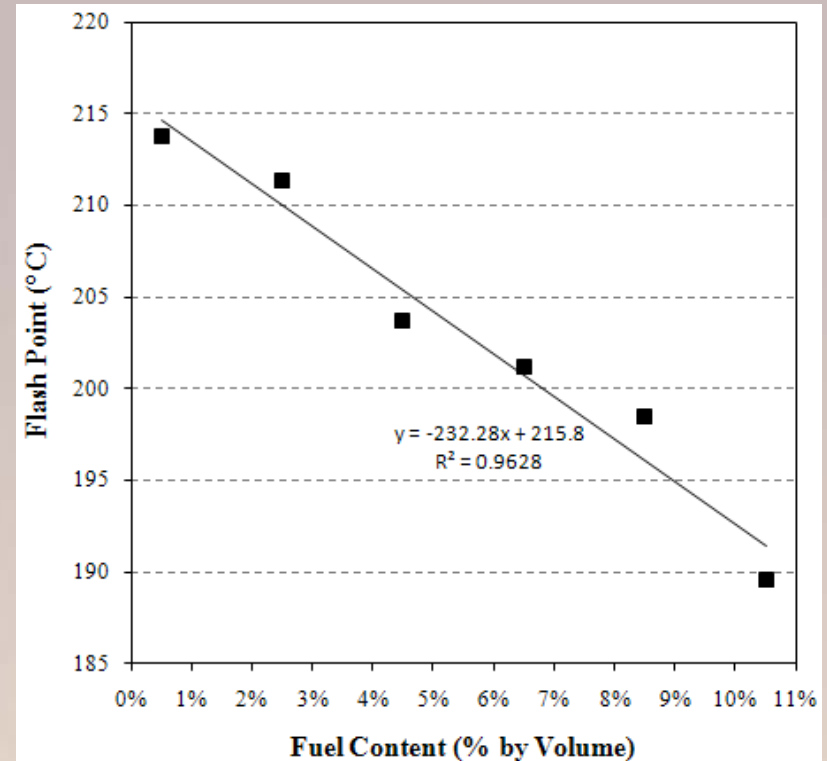
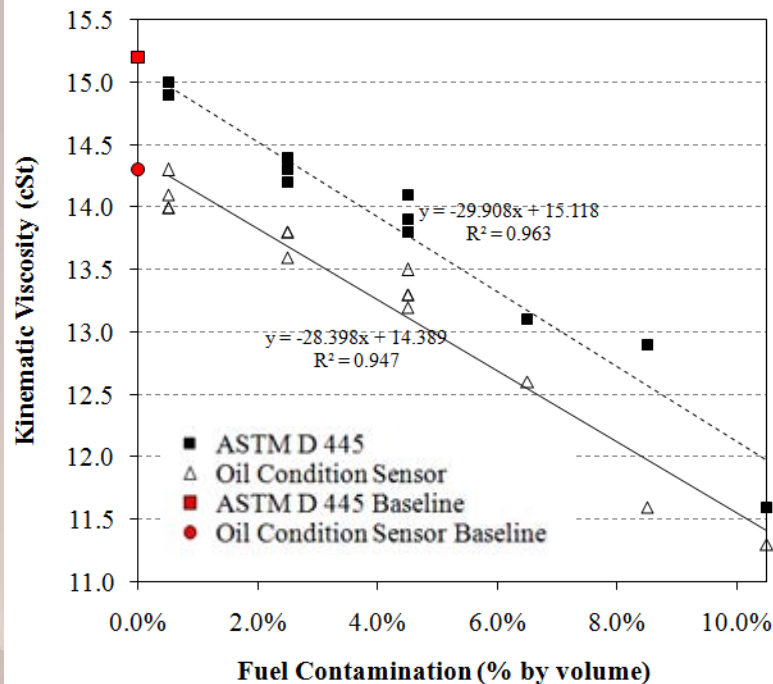
Dielectric Constant: Thermal Cycle Results



- Strong dependence of dielectric constant trends on the lubricant additive package.

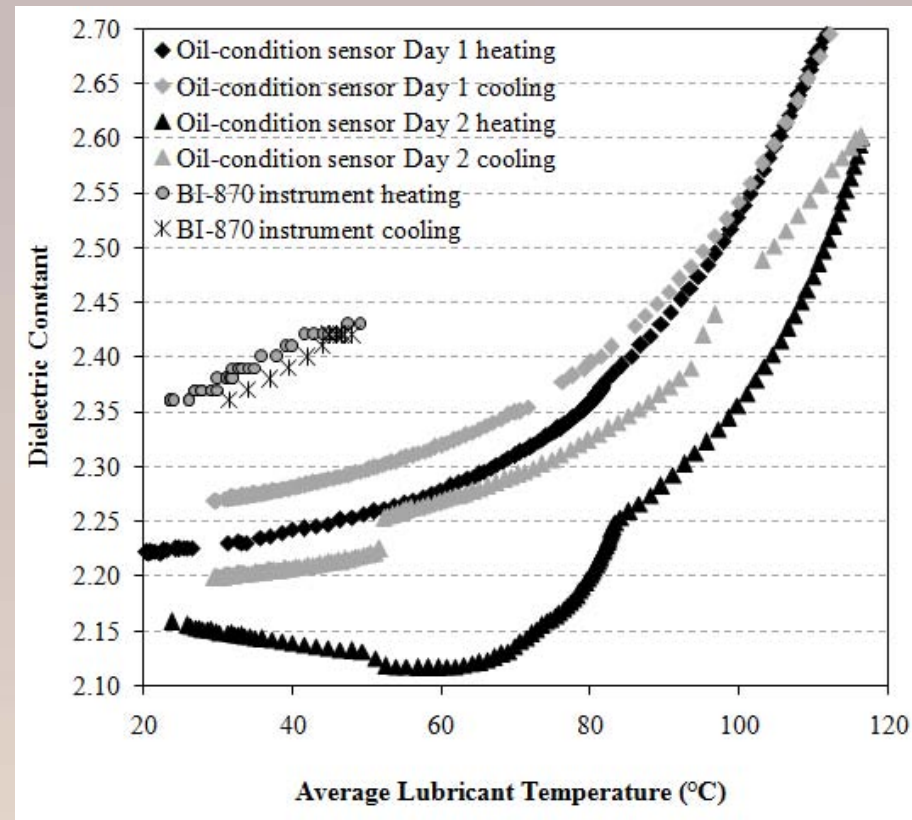
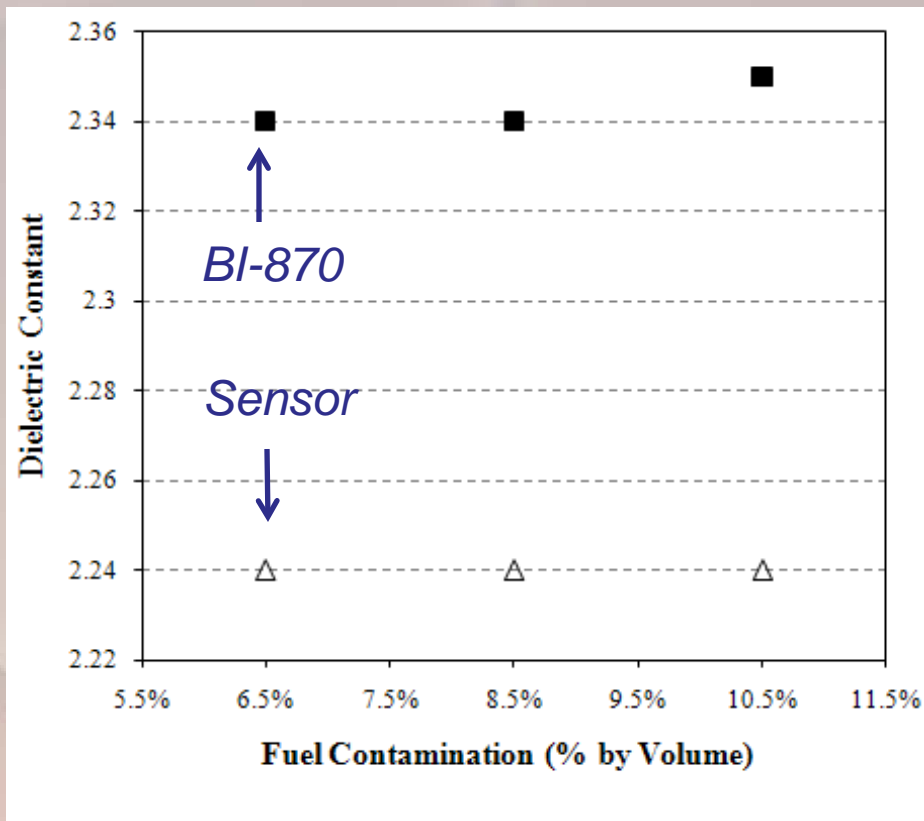
Results: Fuel-Contaminated Oil (1)

Kinematic Viscosity At 100°C For Various Fuel Contamination Levels



- Condemning limit for kinematic viscosity (18%) was reached at fuel concentrations of 9.4% (ASTM) and 7.4% (sensor)
- The flash point (ASTM D 92) decreased by 11.8 % from the baseline measurement as fuel contamination increased from 0.5% to 10.5%

Results: Fuel Contaminated Oil (2)

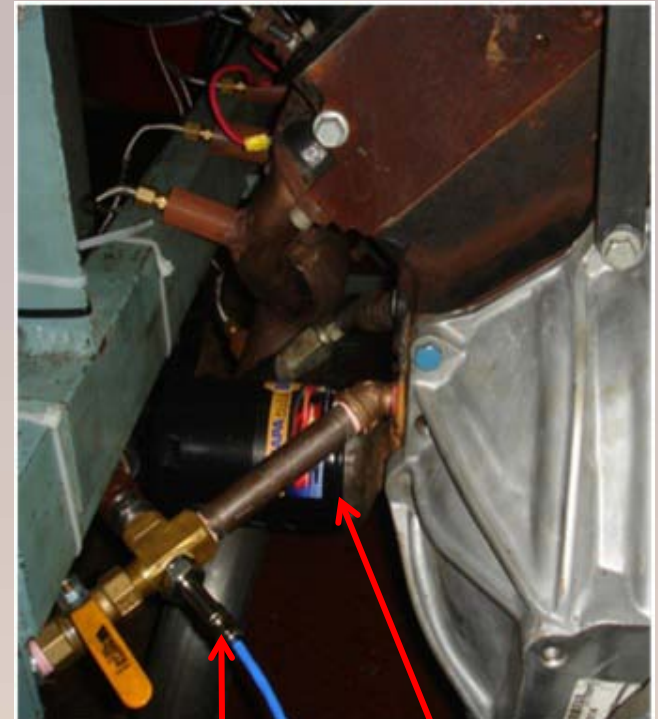


- Dielectric constant measurements are marginally insensitive to fuel contamination
- Dielectric constant trends measured during a thermal cycle are similar between non-contaminated and fuel-contaminated oil samples



Engine Experiments: Initial Tests

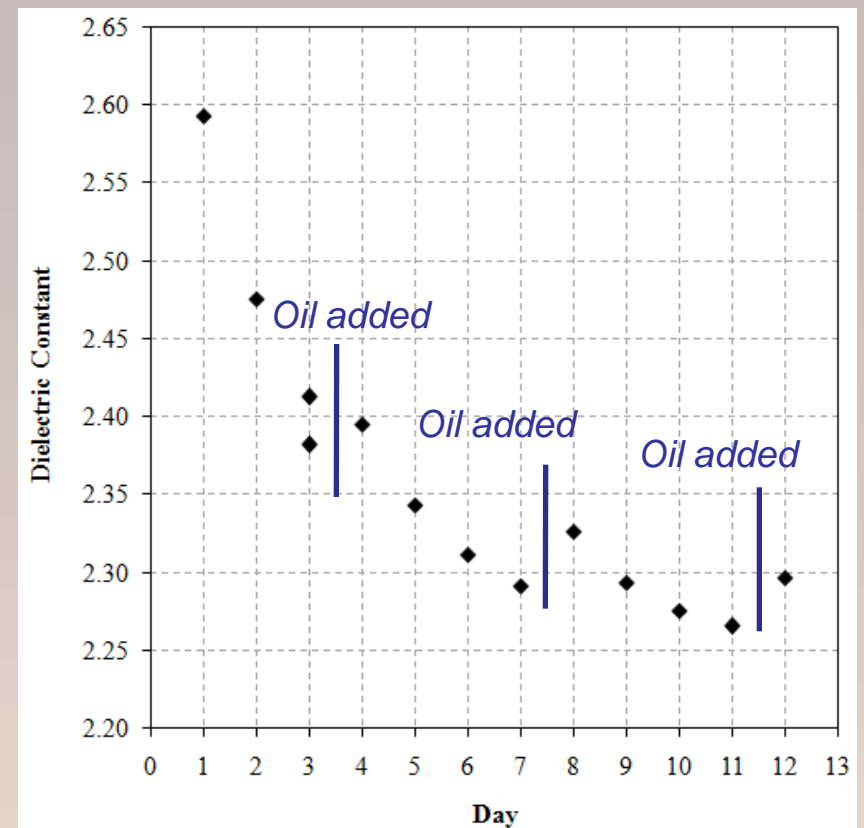
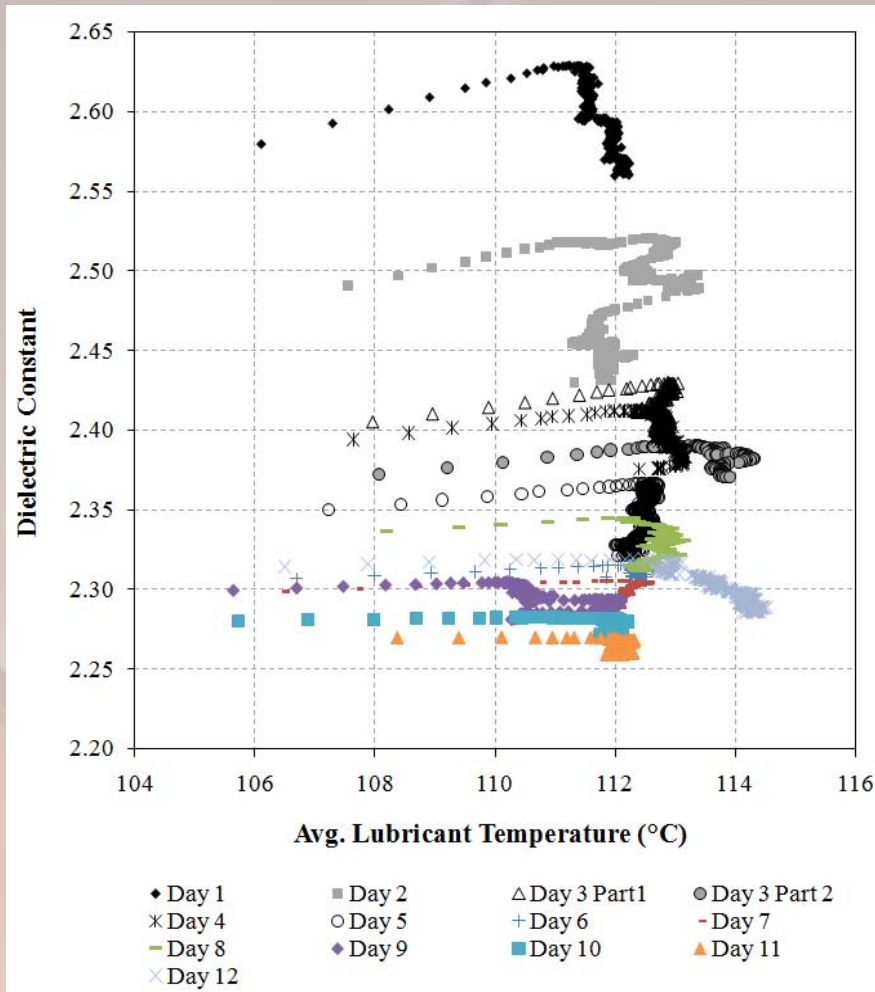
- Objective
 - Quantify changes in the physical properties of the lubricant as a function of engine operating time
- Experimental setup
 - Diesel engine
 - Sensor installed prior to oil filter
 - Operated for 73 hrs at 2,200 RPM and 75% maximum load
 - Oil sampled after the warm-up period and then approximately every 6 hrs. in 150mL increments



oil sensor

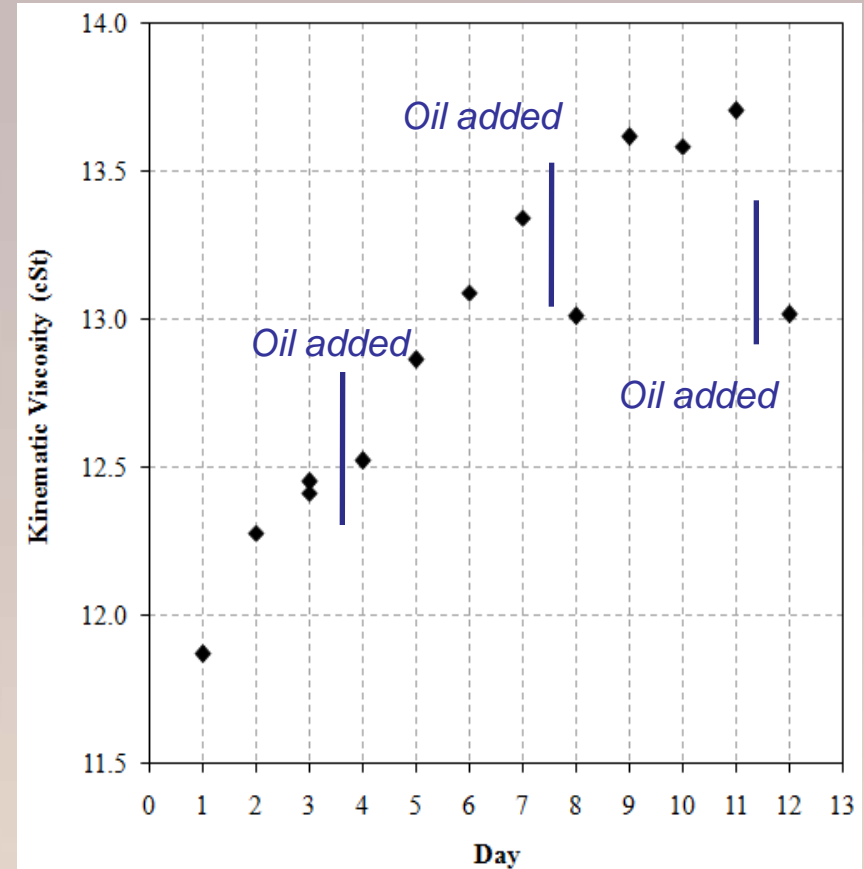
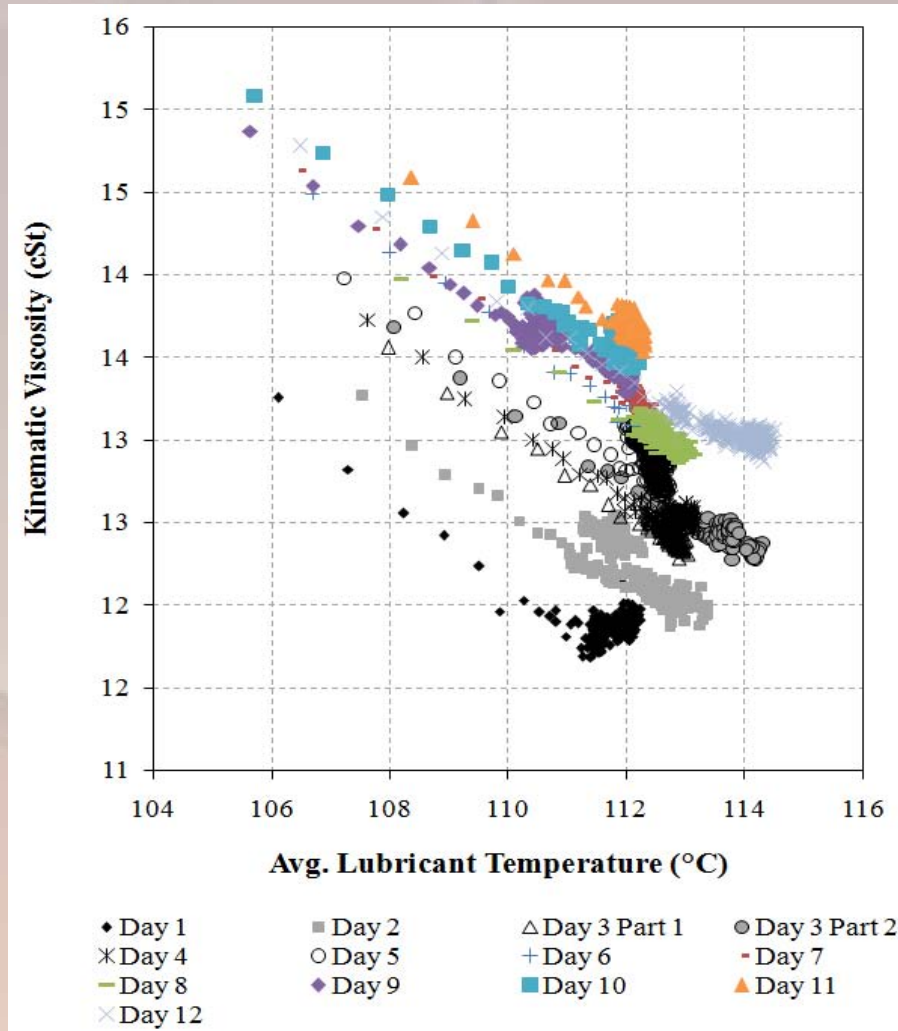
oil filter

Results: Dielectric Constant



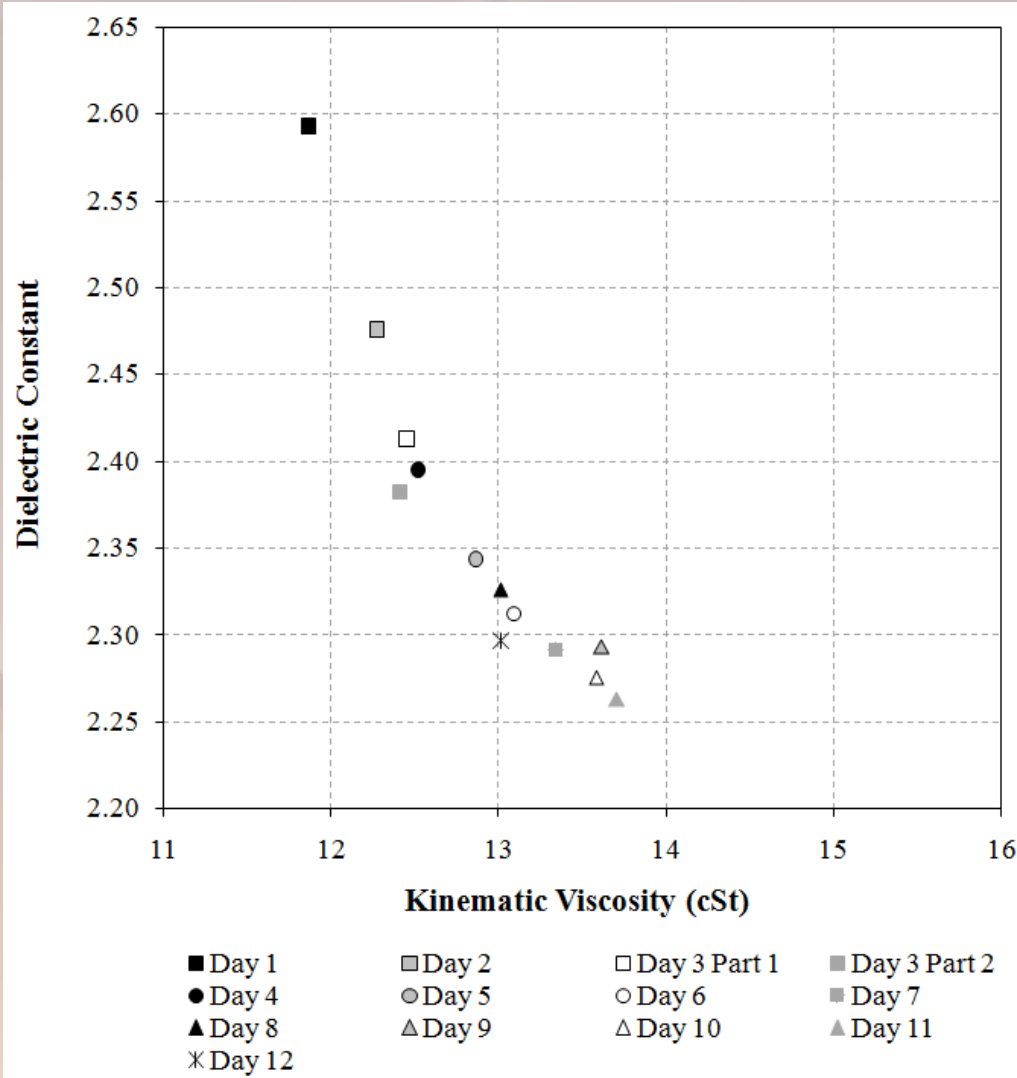
- Decrease of 11% over the course of engine tests
- Increase of 1.5% upon the addition of new oil

Results: Viscosity



- The viscosity increased by 10% over the course of engine tests
- Detected increase of 4% upon the addition of new oil

Results: Property Trends



- The increase in dielectric constant might be attributed to additive depletion
- Increase in oxidation by-products causes a viscosity increase
- A simultaneous decrease in viscosity and increase in dielectric constant suggests the additive package depletion to have a dominant effect



Conclusions

- **Baseline measurements**
 - Kinematic viscosity
 - Sensor output and ASTM D445 agree within 6%
 - Dielectric constant
 - Sensor output and reference instrument agree within 6%
- **Fuel-contaminated oil**
 - Kinematic viscosity
 - As fuel contamination increases to 10.5%, the lubricant viscosity decreases by 21.5% (sensor) and 23.7% (ASTM)
 - Dielectric Constant
 - Marginal sensitivity to fuel contamination (0.5% to 10.5% by vol.)
- **Engine experiments**
 - Dielectric constant decreased 11%
 - Viscosity increased 10%
 - Correlation between dielectric constant and viscosity



Research Areas for Future Work

- Establish a dielectric constant threshold indicative of oil degradation
- Quantify correlations between thresholds in lubricant properties
 - Response surface methodology
- Quantify correlations in lubricant properties over longer periods of engine operation



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